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Concentrations of Nicotine, RSP, CO and CO_2 in Nonsmoking Areas of Offices Ventilated by Air Recirculated from Smoking Designated Areas

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The exposure of nonsmokers to environmental tobacco smoke (ETS) when smoking is relegated to designated areas that are not separately ventilated is of considerable interest. Concentrations of nicotine, respirable suspended particles (RSP), carbon monoxide (CO), and carbon dioxide (CO_2) were measured in offices under different conditions of smoking regulation: smoking prohibited; smoking prohibited areas receiving recirculated air from designated smoking areas; smoking and nonsmoking sections of these designated smoking areas. Nicotine was collected by pumping air for periods of 1-8 hr at 1 L/min through sampling tubes containing a styrene divinylbenzene copolymer. RSPs (3 μm cut-off) were measured using an optical side scattering instrument. CO was measured by a direct reading electrochemical analyzer and CO_2 by colorimetric detector tubes. Detection of nicotine in nonsmoking office areas that received recirculated air from smoking designated areas required sampling times of 4 hr or more. Nicotine levels in such offices were approximately 1.0 μg/m³. RSP, CO and CO_2 concentrations were approximately the same in these offices as compared to nonsmoking offices not exposed to recirculated air from smoking areas. Providing a designated but not separately ventilated smoking area appears to be effective in eliminating most components of ETS from nonsmoking office work areas.

Introduction

A number of municipalities (San Francisco and Vancouver being leading examples) have passed bylaws to regulate smoking in public buildings. In principle these bylaws apply to public buildings and places of employment and establish a norm of no smoking except in smoking areas designated by the employer or proprietor. The Canadian and American Federal Governments are preparing to develop approaches to regulate smoking in workplaces under federal jurisdiction. Provincial and state governments are making similar preparations.

Four options are available to regulate office smoking:

1. Prohibiting smoking outright;
2. restricting smoking to designated areas that are ventilated separately;
3. restricting smoking to designated areas that are not ventilated separately; and
4. providing some framework by which an adjustment between smoking and nonsmoking workers may be achieved without directly regulating the placement of smokers.

The third option, that of providing a designated but not separately ventilated smoking area, appears to be the most frequently adopted procedure. A certain proportion of a building's population will demand a location where they may be allowed to smoke (for example, employees on their coffee and lunch breaks, members of the public waiting for services, or persons who are residents of the building—such as in prisons or hospitals.) Governments and the private sector own, operate and rent a wide variety of different buildings, however, most of these buildings do not offer separate ventilation for different locations. To provide separate ventilation would not only be costly in many instances but very often physically impossible. Thus, the least disruptive and costly solution for many buildings appears to be the setting aside of designated but not separately ventilated smoking areas.

A question of considerable interest is the extent to which designated but not separately ventilated smoking areas are effective in decreasing exposure to environmental tobacco smoke (ETS) in nonsmoking areas. This project was designed to provide some information on that question.

The authors report here the outcome of a series of measurements of nicotine, respirable suspended particles (RSP), carbon monoxide (CO) and carbon dioxide (CO_2) obtained in the following locations:

1) two cafeterias, each having smoking and nonsmoking areas;
2) four nonsmoking floors which received air recirculated from a ventilation system common to one of the cafeterias; and
3) two nonsmoking offices with independent ventilation systems which, therefore, did not receive air recirculated from designated smoking areas.

Methods

Air sampling for nicotine, RSP, CO and CO_2 and an observation of the number of office occupants present and cigarettes smoked was undertaken in two adjacent buildings

(Vancouver City Hall and City Hall Annex): Building A, which is a sealed, mechanically ventilated building, and Building B, which has opening windows and mechanical ventilation only in selected areas.

Building Description

Building A is a 4-story sealed office building with 2 levels of underground parking. Each of the 4 floors contains approximately 1390 m^2 (15 000 ft^2) of office space. Fresh air from an intake at ground level is supplied to an air-handling unit in the basement mechanical room. This fresh air is filtered, conditioned and then supplied unmixed to air induction units located at exterior walls. Air is returned, via ceiling return grates, to a second air-handling unit in the basement, which exhausts a portion of the return air, adds makeup air (minimum of 20%), and filters, conditions and returns the air to the occupied space via ceiling diffusers. As a result, indoor air from different parts of the building and different floors is mixed. Smoking is prohibited in all work areas and public areas of the building and is permitted only in the smoking section of the fourth floor cafeteria which is not separately ventilated.

Building B is a 12-story, unsealed building with opening windows and, originally, no mechanical ventilation system. Most areas are passively ventilated by building leakage while separate ventilation systems have been incorporated in only a few areas. In the offices where measurements were taken, rooms with exterior walls have opening windows. Additional ventilation is supplied to the central zone of each of these offices by an air-handling unit which receives fresh air from an intake at ground level. The zone air-handling unit feeds conditioned air to a supply-air plenum (in the ceiling space) where individual fan-coil units temper the air again and deliver it to the occupied space below. Air which has not been exhausted through windows or doors is returned to the ceiling plenum and again tempered by the fan-coil units. These systems, therefore, have no ducting common to other areas of the building. Smoking is prohibited in all work areas and public areas in the building except the smoking section of the cafeteria (which is located in the basement). Heated/cooled air is supplied separately to the cafeteria and exhausted through windows.

Sampling and Occupant Observation

Three samples were taken in each of the smoking and nonsmoking sections of the cafeterias of Buildings A and B; two samples on each of the four floors in nonsmoking offices of Building A; two samples in the nonsmoking offices of Building B; and two samples of RSP outdoors.

Samples for nicotine were obtained using a portable air sampling pump housed inside a briefcase. Because of the effect of air sampling on occupant behavior,[11] the sampling apparatus was designed to collect samples in an unobtrusive manner. Nicotine samples were collected by pumping air at 1 L/min through sorbent tubes containing XAD-4 resin, a styrene divinylbenzene copolymer. The sorbent tubes contained 80 mg of resin in the front (primary) section and 40 mg in the rear (secondary) section. Samples were collected for 1 hr each in the cafeteria locations and for periods of 2, 4 or 8 hr at other sampling sites. Respirable suspended particles (3.5 μm cutoff) were determined using a P-5H digital dust indicator (Sibata Scientific Technology, Tokyo, Japan) which measures light side-scattered by suspended particles. The unit was calibrated at the factory to monodispersed stearic acid particles with a mean diameter of 0.3 μm. The unit usually measured respirable particles for the entire sampling period, depending on battery charge. Approximately midway into the 1- or 2-hr air sampling period, CO and CO_2 concentrations were measured at the sampling locations. (CO and CO_2 were measured more often during 4- and 8-hr sampling periods.) CO was measured using a direct-reading electrochemical analyzer (Nova 310 L, Nova Analytical Systems, Inc., Hamilton, Ontario) housed in a flight case. CO_2 was measured using colorimetric detector tubes (Gastec, Gastec Corporation, Yokohama, Japan) and a manual sampling pump.

During a sampling period, the number of occupants in a predefined observation area and the number of cigarettes smoked in that area were observed and recorded. The observation areas were defined by visual configurations and reliability of surveillance of the observable office area. For purposes of comparison, number of persons and cigarettes smoked were calculated per 10 m^3 where applicable. At the completion of sampling, the sorbent tubes were refrigerated until analysis.

Analysis

In the chemical analysis of nicotine, resin beads in the sorbent tubes were transferred to gas chromatograph autosampler vials to which were added 50 μL of quinoline (100 mg/L) to serve as an internal standard and 1 mL of ethyl acetate as an extraction solvent. Triethylamine (0.01% by volume) was added to the extraction solvent to prevent adsorptive losses of nicotine onto the glass autosampler vials. Samples and spiked standards then were placed on an automatic shaking device and shaken for 30 min. A Hewlett-Packard Model 5880A or Model 5830A gas chromatograph equipped with a nitrogen-phosphorus detector was employed in conjunction with an autosampler and a GC terminal to determine peak areas of the nicotine and compare them with the areas obtained from nicotine standards. The assayed nicotine was corrected for the desorption efficiency (usually 94%) of the particular lot of XAD-4 resin used in sampling. Final nicotine results were divided by the volume of air sampled to yield results in μg/m^3. The rear (backup) sections of sorbent tubes were analyzed separately and, except for one case, always yielded nicotine determinations less than the limit of detection, thus indicating no breakthrough of nicotine past the primary section. [The authors' procedure, by and large, is based on the National Institute of Occupational Safety and Health (NIOSH) method.[12]]

Respirable suspended particles were estimated by converting the digital counts of particles per sampling time to an average count per minute. A background count of 5 counts per min was subtracted from the average to yield RSP values in μg/m^3.

Results

Table I summarizes measurements for RSP, CO, CO_2, nicotine; average number of persons per 10 m^2; and average number of cigarettes smoked per hour per 10 m^2 (where applicable). Because of the large variability and suspected skew of measures, means, medians and ranges are given. Measurements in the cafeteria smoking areas each are based on 6 samples as are measurements in the cafeteria nonsmoking areas. Because there were no perceptible differences between cafeterias in Buildings A and B, both for smoking and nonsmoking areas, their data have been merged. Measurements in nonsmoking office areas in Building A are based on 8 samples, and measurements in nonsmoking areas in Building B are based on 2 samples.

There were significantly more persons per unit area in the cafeterias than in the nonsmoking offices. The numbers of individuals per 10 m^2 in smoking and nonsmoking areas of cafeterias, however, were approximately the same. As might be expected, both CO and CO_2 levels were higher in the smoking than nonsmoking areas of the cafeterias. This also was true for RSPs. Nicotine levels averaged 14.0 $\mu g/m^3$ in the smoking area and 6.2 $\mu g/m^3$ in the nonsmoking area of the cafeterias. The drop in RSPs and nicotine from smoking to nonsmoking areas of the cafeterias is quite steep and attests to the rapid dilution of ETS.

Contributions to RSP, CO and CO_2 that are caused by smoking in the designated smoking area are diluted further in the recirculated air. This dilution can be seen from a comparison of measurements in the office areas of Building A with Building B. Concentrations of RSP, CO and CO_2 in Building A's nonsmoking areas, which received recirculated air from the smoking area, are approximately the same as those measurements taken in Building B, which did not receive any such recirculated air (also see Table II). Of special interest are measurements of nicotine. It is important to keep in mind that the detection of nicotine in air, in the dilute quantities in which it may be present, requires a lengthy sampling procedure. As the concentration of nicotine in air decreases, larger air samples must be obtained to detect that concentration. For the method used here, a 2-hr sample at 1 L/min would detect nicotine concentrations greater than 0.8 $\mu g/m^3$. Of 4 samples taken for 2 hr each, not a single sample detected a concentration above 0.8 $\mu g/m^3$. For a 4-hr sample at 1 L/min, the lower level of detection is 0.4 $\mu g/m^3$. At that level, 1 positive detection at a concentration of 1.0 $\mu g/m^3$ was made in 1 out of 3 samples. For the 1 sample taken for 8 hr, the lower level of detection was 0.2 $\mu g/m^3$. That sample measured a concentration of 0.8 $\mu g/m^3$ (findings summarized in Table II).

Discussion

Studies of office air quality have demonstrated that significant reductions in ETS related RSP may be achieved in nonsmoking areas when smoking is limited to designated areas that are not ventilated separately.[11] The extent of involuntary exposure to ETS, however, best may be established quantitatively when nicotine is used as the marker.* It has been suggested[12] that advances in measurement technology may provide grounds for reliance on nicotine as a general indicator of ETS. Other components of ETS may be less useful for developing an ETS exposure index. ETS components are complex and variable and also include many constituents similar to those emitted from other sources.[10]

*The observation that nicotine in sidestream smoke is mainly in the vapor phase while in mainstream smoke it is more in the particulate (deposit) phase poses no obstacle to the use of nicotine as an index of ETS infiltration because building occupants are not exposed to mainstream smoke unless they actively do smoke. The nicotine concentration obtained from sampling the air is a representative sample of ambient ETS inhaled by nonsmokers.

TABLE I
Comparison of ETS Related Air Quality Parameters in Nonsmoking Work Areas and Designated Smoking Areas

		RSP[a] ($\mu g/m^3$)	CO (ppm)	CO_2 (ppm)	Nicotine ($\mu g/m^3$)	Persons /10 m^2	Cigarettes /hr/10 m^2
Smoking areas of Cafeterias A & B combined	Mean	70	3.9	690	14	1.8	1.2
	Range	23–129	1.1–11.4	450–1000	<1.6–43.7	0.79–3.42	0.53–1.67
	Median	74	2.5	660	11	1.8	1.2
Nonsmoking areas of Cafeterias A & B combined	Mean	32	2.6	560	6.2	1.7	
	Range	15–57	1.2–4.5	400–700	<1.6–10.9	0.79–2.8	NA[b]
	Median	26	2.4	580	7.9	1.7	
Nonsmoking office area, Building A	Mean	6	1.8	490		0.73	
	Range	4–11	1.3–2.3	400–580	[c]	0.29–1.8	NA
	Median	6	1.7	500		0.46	
Nonsmoking office area, Building B	Mean	7	1.35	450		0.9	
	Range	6–8	1.3–1.4	400–500	[c]	0.53–1.28	NA
	Median	7	1.35	450		0.9	

[a]Mean outdoor RSPs were 10 $\mu g/m^3$.
[b]NA = not applicable
[c]See Table II

TABLE II
Nicotine, RSP, CO and CO_2 Concentrations in Eight Locations in a No Smoking Office Area that Receives Recirculated Air from a Smoking Designated Area and in Two Locations without Such Recirculation[a]

	Location	Sample Time (hr)	Nicotine ($\mu g/m^3$)	RSP ($\mu g/m^3$)	CO (ppm)	CO_2 (ppm)	Persons /10 m^2
Recirculated air	1	2	<0.8	6	1.7	550	0.50
	2	2	<0.8	5	2.3	500	0.42
	3	2	<0.8	5	1.3	400	1.00
	4	2	<0.8	4	2.0	500	0.36
	5	4	<0.4	11	2.2	>50	0.39
	6	4	<0.4	5	1.7	450	0.28
	7	4	1.0	6	1.7	500	1.02
	8	8	0.8	6	1.6	450	0.98
No recirculated air	9	[b]	[b]	6	1.4	400	0.53
	10	[b]	[b]	6	1.3	500	1.28

[a]Sampling time for nicotine ranged from 2 to 8 hr.
[b]Nicotine was not measured because these offices could not receive ETS from any source.

Air sampled for 2 hr at 1 L/min (using the NIOSH protocol) reliably measures nicotine levels that are larger than 0.8 $\mu g/m^3$. Levels of nicotine appear to be at or below that concentration in offices in which smoking is prohibited but which receive air recirculated from smoking designated areas. To give meaning to such trace values, the exposure of an office worker to nicotine at 1 $\mu g/m^3$ for 1 hr can be calculated roughly. Given a breathing rate of 0.48 m^3/hr for the level of activity required during normal office work,[6,8] an office worker would breath air containing 0.48 μg of nicotine in 1 hr. This quantity is approximately equivalent to 1/1800 of the nicotine inhaled by actively smoking 1 cigarette (900 μg/cigarette[8b]). Until relatively recently, calculations of a smoker's exposure to cigarette smoke was limited to amounts of materials in the mainstream smoke. Insofar as smokers are spatially close to their cigarette and often inhale relatively undiluted sidestream smoke, existing estimates of smokers' exposure to any component of ETS must be lower than their actual magnitudes. Thus, the nonsmoker probably inhales less than 1/1800 of the nicotine inhaled by a smoker when actively smoking one cigarette, unless this nonsmoker should be standing in very close proximity to a burning cigarette.

Based on these findings, it is the authors' belief that the provision of a designated smoking area appears to be effective in eliminating most traces of ETS from the rest of the office space, even if the designated smoking area is not separately ventilated. An exclusive reliance on regulating smoking while ignoring all other problems besides smoking which may influence the quality of air in the nonindustrial work environment may accomplish little in addressing indoor air quality problems, however, especially in so-called "sick buildings."[7]

If a designated area is made available for smoking in offices where otherwise smoking is not permitted, the designated space should be sufficiently large to prevent overcrowding.

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